# PARIS

**Process Attribution of Regional Emissions**

GA 101081430, RIA

## Inverse estimates of European methane emissions for previous year

| **Milestone M16** | | | |
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# 1. Changes with respect to the DoA (Description of the Action)

N/A

# 2. Dissemination and uptake

This output and/or the methods developed leading to this output will be used in compiling the annexes to the upcoming NIR. This output is also used in WP2 for the reconciliation of top-down and bottom-up national level estimates, and in discussion with stakeholders, national inventory report compilers etc.

# 3. Short Summary of results

Close collaboration between the three modelling groups in the project, University of Bristol, Met Office and EMPA, has resulted in a standardised data format for the output of the inverse models. An intercomparison software tool has been developed across the groups which allows detailed investigation of the different modelling systems to be conducted efficiently and in-depth.

It is possible to make comparisons between, for example, the different models' selection of observational data, the split of uncertainties used by each group into modelled and observational, and the baselines calculated at each measurement site. The development of both this tool and the three models, to output the required information, was carried out by modelling HFC's, measured at 4 European sites. This allowed us to gain an understanding of modelling differences and make changes to the models where necessary. This tool, and the inversion models, are now ready to be used to explore inverse modelling of methane. Monthly InTEM results using 33 stations across Europe (ICOS, national networks) 2018-2023 have been completed. The other modelling systems are nearing completion of their initial methane inversions, and the first inter-comparisons of methane will begin in summer 2024.

The data will become publicly available by linkage with the NIR annex as soon those are published.

# 4. Evidence of accomplishment

## 4.1 Introduction | Background of the milestone

Inverse estimates of methane are made using atmospheric measurements of amount fractions, as well as other observables such as isotope ratios that can provide additional information for sectoral breakdown. Use of atmospheric transport models is necessary to translate these atmospheric measurements into estimates of emissions from the surface. Multiple methods and analyses can be used to couple models with atmospheric data, which can vary significantly, for example through the data filtering methodologies, resolution of the transport model output, transport model setup, and execution of the statistical inversion technique.

Team members have each published their own independent methods and results on the use of their inversion systems in estimating methane emissions (Lunt et. al. 2021, Henne et. al. 2016). PARIS aims to understand the differences between setups, the effects of those differences, and harmonizing, where possible, the inputs and outputs to allow for robust comparability.

Total methane emissions estimates will be derived for Europe across a matrix of transport models and inversion setups:

- University of Bristol: NAME-RHIME, FLEXPART-RHIME,
- Met Office: NAME-InTEM, FLEXPART-InTEM,
- EMPA: NAME-ELRIS and FLEXPART-ELRIS.

In addition, there will be a new ICON-ART-DWD system to enhance German capability. Measurements from ICOS and individual national networks (e.g., UK DECC) will be used.

New methane $\delta^{13}C$ and $\delta D$ data and ethane measurements will be integrated into the inverse modelling systems at a later stage of the project, which will allow estimates of methane emissions from the major source categories (microbial, fossil fuel) for the focus countries where enhanced observations are be available.

In this report on inversion estimates we show results from measurements of total methane across Europe from the Met Office setup (NAME-InTEM) and describe the work of the other groups working on this (University of Bristol, EMPA and DWD).

## 4.2 Scope of the milestone

This milestone will provide inverse CH4 estimates to be used in compiling the annexes to the upcoming NIR. This document reports on the progress of inversion estimates of methane. These estimates will be made on a recurring basis across the course of the project. This milestone report shows the progress in delivery of the systems to make these estimates together with some of the first results. The results and methodologies will feed into the NIR annex work that is due later in the year.

## 4.3 Content of the milestone

Significant work has been undertaken to prepare for the first national inventory comparison in Autumn 2024. Intensive exchange between three of the modelling groups (University of Bristol, Met Office and EMPA) has resulted in standardised data formats for inverse modelling enabling the rapid interchange of atmospheric transport model (NAME, FLEXPART) and three of the inverse modelling systems (RHIME, InTEM, ELRIS). Comprehensive inter-comparison software has been co-developed across the groups. This new tool enables detailed investigation of the different modelling systems to be conducted efficiently and in-depth. For methane, monthly InTEM results using 33 stations across Europe (ICOS and national networks) for 2018-2022 have been completed. Fig. 1 shows the monthly InTEM posterior methane flux estimates for two different European regions as detailed below. Fig. 2 shows example output for 3 sites (Tacolneston, Trainou and Lutjewad), using the inter-comparison software which facilitates easy plotting of observational data against posterior model mole fractions (with associated uncertainties) at any of the observation sites, to assess both individual model performance and differences between models.

Fig. 3 shows the emission flux maps from InTEM which result from averaging the monthly inversions, throughout the 2018-2022 period (panel (a)), summer months only (panel (b), winter months only (panel (c)) and the difference between summer and winter fluxes in panel (d). Observation sites are marked as blue triangles.

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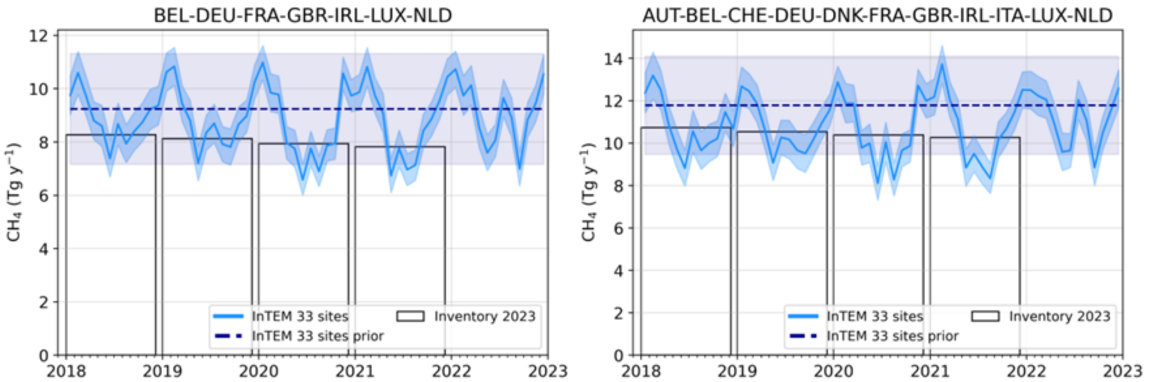


**Fig. 1:** Monthly InTEM posterior methane flux estimates (light blue) using 33 sites compared to prior mean flux estimate (dashed dark blue) and inventory flux estimates as reported to the UNFCCC (black bars) in 2023. These estimates are given for two broad regions, which are defined by their 3-character ISO-3166 codes.

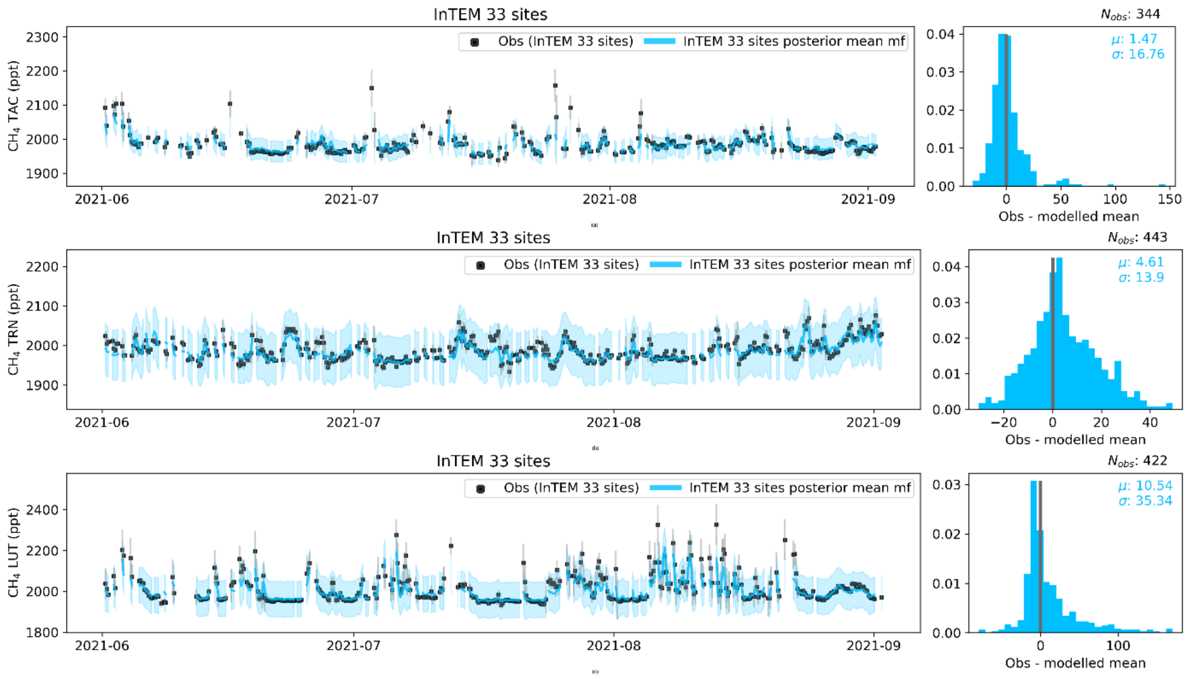


**Fig. 2:** Three months of observed (black squares) and InTEM posterior modelled (blue circles and shading) methane mole fractions from three example sites: (a) Tacolneston (TAC) England, (b) Trainou (TRN) France and (c) Lutjewad (LUT) Netherlands. Statistics representing the modelled mole fractions' fit to observations over this period are given in the histogram plots.

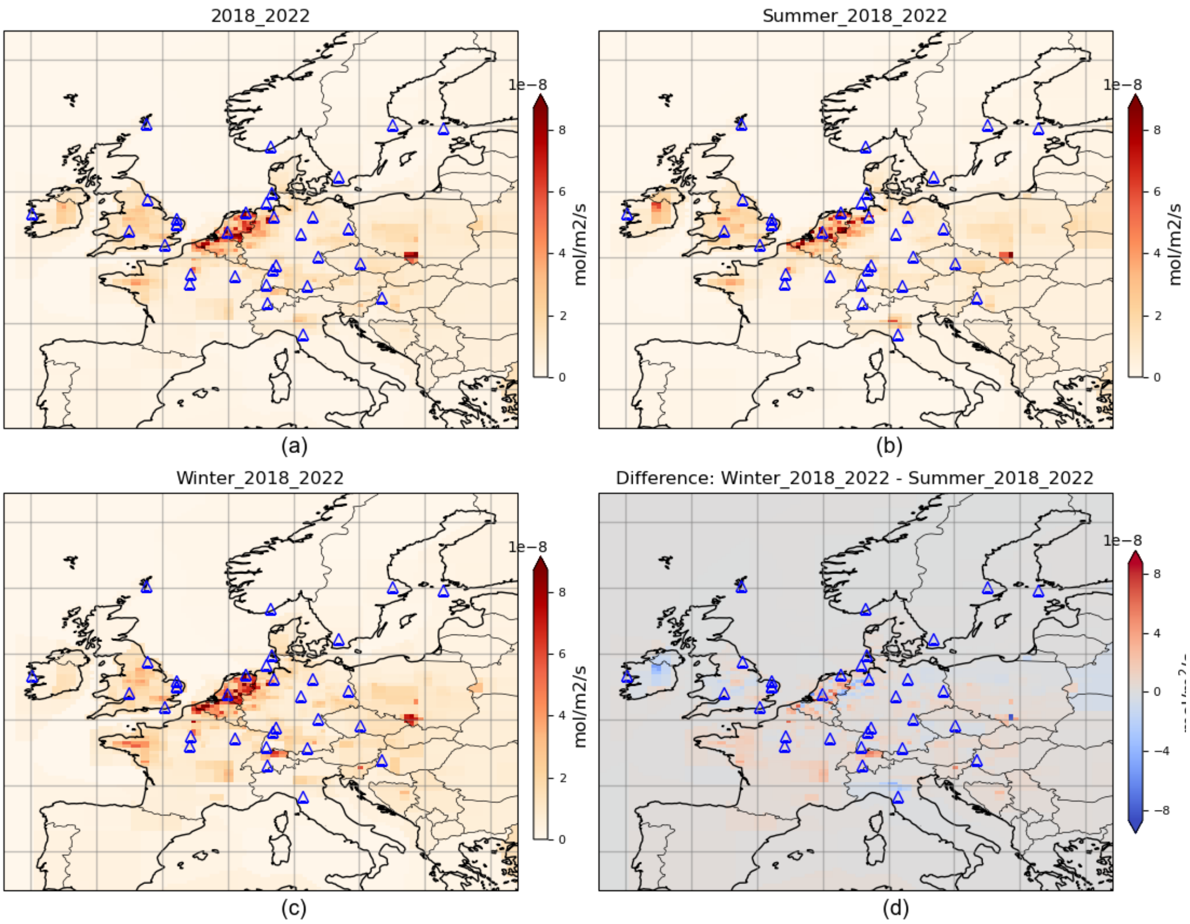


**Fig. 3:** Panel (a) InTEM mean posterior methane flux across Western Europe, averaged from monthly inversions between 2018 and 2022. Panel (b) InTEM mean posterior methane flux across Western Europe, averaged from monthly inversions for the months June, July & August from 2018 and 2022. Panel (c) InTEM mean posterior methane flux across Western Europe, averaged from monthly inversions for the months December, January & February from 2018 and 2022. Panel (d) Difference map of winter minus summer. Observation site locations are shown as blue triangles.

The other modelling systems are nearing completion of their initial inversions, and the first inter-comparisons of methane will begin in summer 2024. Empa have set up and completed atmospheric transport simulations (FLEXPART driven by ECMWF inputs) for inverse modelling for 40 sites across Europe and the period 2018-2022. Hourly footprints (source sensitivities) were produced using the same output grid definition as applied by the Met Office for the NAME model. First preliminary $CH_4$ inversions based on these transport simulations were calculated using Empa's ELRIS inversion system. The University of Bristol have completed an initial inverse model run using NAME footprints for 13 sites across Europe. Initial comparisons will focus on the sensitivity of model output to the different sites selected, with all models running all selections of sites, with the aim of understanding the impact of elevated measurement sites on the methane estimates. Initial runs have been undertaken using the Edgar v8 dataset. Subsequent estimates will be made after combining this dataset with suitable wetland emission estimates.

## 4.4 Conclusion and possible impact

The initial set up for the operational systems for inverse estimates of methane for Europe across the groups in this consortium are close to being ready and preliminary results have been shown from InTEM in preparation for later reporting under the NIR annexes. For this first reporting period we are yet to make a rigorous comparison between different model and inversion setups. This will occur over the coming months.

## 4.5 References

Lunt, M. F., Manning, A. J., Allen, G., Arnold, T., Bauguitte, S. J.-B., Boesch, H., Ganesan, A. L., Grant, A., Helfter, C., Nemitz, E., O'Doherty, S. J., Palmer, P. I., Pitt, J. R., Rennick, C., Say, D., Stanley, K. M., Stavert, A. R., Young, D., and Rigby, M.: Atmospheric observations consistent with reported decline in the UK's methane emissions (2013–2020), Atmos. Chem. Phys., 21, 16257–16276, https://doi.org/10.5194/acp-21-16257-2021, 2021

Henne, S., Brunner, D., Oney, B., Leuenberger, M., Eugster, W., Bamberger, I., Meinhardt, F., Steinbacher, M., and Emmenegger, L.: Validation of the Swiss methane emission inventory by atmospheric observations and inverse modelling, Atmos. Chem. Phys., 16, 3683–3710, https://doi.org/10.5194/acp-16-3683-2016, 2016

# 5. History of the document

| Version | Author(s) | Date | Changes |
|---|---|---|---|
| 1.0 | Arnold, Ganesan, Manning, Henne | 18 June 2024 | First draft report |
| | Redington | 03 July 2024 | Second draft report |
| | Walter | 12 July 2024 | Final formatting and upload |